**Fermi National Accelerator Laboratory**

# Tevatron Injection Timing

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# Disclaimer

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## 1   Introduction

Bunched beam transfer from one accelerator to another requires coordination and synchronization of many ramped devices. During collider operation timing issues are more complicated since one has to switch from proton injection devices to antiproton injection devices. Proton and antiproton transfers are clearly distinct sequences since protons and antiprotons circulate in opposite directions in the Main Ring (MR) and in the Tevatron. The time bumps are different, the kicker firing delays are different, the kickers and lambertson magnets are different, etc.

Antiprotons are too precious to be used for tuning purposes, therefore protons are transfered from the Tevatron back into the Main Ring, tracing the path of antiprotons backwards. This tuning operation is called "reverse injection". Previously, the reverse injection was handled in one supercycle. One batch of uncoalesced bunches was injected into the Tevatron and ejected after 40 seconds. Then the orbit closure was performed in the MR. In the new scheme the lambertson magnets have to be moved and separator polarities have to be switched, activities that cannot be completed in one supercycle. Therefore, the reverse injection sequence was changed. This involved the redefinition of TVBS clock event $D8 as MRBS $D8 thus making it possible to inject 6 proton batches (or coalesced bunches) and eject them one at a time on command, performing orbit closure each time in the MR.

Injection devices are clock event driven. The TCLK is used as the reference clock. Certain TCLK events are triggered by the MR beam synchronized clock (MRBS) events. Some delays are measured in terms of MRBS ticks and MR revolutions. See Appendix A for a brief description of the beam synchronized clocks.

## 2   Proton Injection in the Collider Mode

Table 1 shows the clock events and the delays involved in the proton transfer during collider operations. Protons are injected into the MR at A0 and accelerated to 150 GeV on a $2B cycle. Proton injection into the Tevatron at 150 GeV involves time bumps in the MR and in the Tevatron. FERMILAB TM-1790 [1] contains more details about the time-bumps involved in the beam transfer. In this note timing issues are stressed.

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| TCLK Event | Delay | Description |
|---|---|---|
| PROTON INJECTION (COLLIDER) | | |
| 00 |  | Supercycle reset |
| 61 | <00> 0.1 sec | DFG:Start |
| 2B | TLG | Reset: MR cycle for collider (proton). |
| 4D | TLG | Reset: Proton injection. |
| 22 | <2B> 0.6 sec | MR:Start ramp to 150 GeV. |
| 25 | <2B> 2.5048 sec | MR:Start of flattop at 150 GeV. |
|  | <2B> 5.5 sec | Start proton coalescing. |
|  | <4D> 7.0 sec | Start the MR time bump (M:MRD46, M:MRE17). (these are now 465 cards) |
|  | <4D> 7.5 sec | Start the Tev time bump (handled by E0 465 cards, see Operations Bulletin 1233) |
|  | <4D> 7.6 sec | Start the MR time bump (T:IBMP1, T:IBMP2, T:IBMP3)(160 cards). |
| Sequencer complex command: "inject protons Pn" (n=1-6) | | |
| C1 |  | Align MRBS A-Marker with the TVBS A-Marker. Occurs only once after "setting at 150 GeV". |
|  |  | Enable MRBS $7C. |
| 7C → 5C (MRBS) | <4D> 13.80 sec | Initiate MR → Tev transfer. |
|  |  | Disable MRBS $7C. |
| end "inject protons Pn" | | |
|  | MRBS <7C> 2.044 mrev | Fire MR C48 kicker. Rise time is 360 nsec. Flattop length ≈ 21μsec. |
|  | MRBS <7C> 1.975 mrev | Fire Tev E17 kicker. Rise time is 550 nsec. Flattop length 2-21 μsec (adjustable). |
|  |  | These delays take into account the transit time for the clock pulse to travel around the ring and the position of the beam relative to the clock pulse. |
| 26 | <2B> 13.9748 sec | End of MR $2B flattop (150 GeV). |

Table 1: Proton injection timing in the collider mode. The transfer cogging offsets are 0,186,371,557,742,928 RFCYC, for P1 through P6, respectively. Note that kickers are referenced to MRBS $7C not TCLK $5C.

# 3  Antiproton Injection

Antiprotons are injected into the MR at F17 and accelerated to 150 GeV on $2A cycles. Since the antiproton kicker in the MR (at E17) is a short distance away from E0, the time bump (T:IBMP1, T:IBMP2, T:IBMP3) is not necessary. Due to differences in the MR-C48 and MR-E17 kickers and due to the proximity of the MR-E17 Kicker to E0, the kicker timings are very different than the ones in $2B cycle. The cogging offsets are also different.

In the transfer cogging there is no energy or path length manipulation in the Tevatron. The MR energy is manipulated, however, for this correction. The A-Marker of the MRBS is delayed with respect to the TVBS A-Marker. The TVBS A-Marker remains fixed with respect to Tev RF while the MR RF is phase shifted. Using transfer cogging offsets one can inject a proton or an antiproton bunch into a particular Tevatron bucket. The antiproton injection sequence is summarized in Table 2.

# 4  Reverse Injection

The antiproton injection line is tuned with protons by reverse injecting them from the Tevatron into MR. This simulates the forward antiproton injection. The reverse injection timing system has been changed. In the previous scenario, a single proton bunch was injected into the Tevatron on a $2B cycle. The cogging offset for this bunch was 0 RFCYC. Forty seconds later in the supercycle, the same bunch was reverse injected into MR on a $20 cycle. In the new timing scheme, six proton bunches can be injected into the Tevatron on six $2B cycles, and then reverse injected into MR on six $20 cycles on demand. The reverse injection request is issued by the sequencer.

Transfer cogging can only be done in the MR RF system. Therefore, a MRBS clock event has to fire the kickers for reverse transfer of protons. In the previous scenario, a TVBS clock event, $D8, was used. Since $D8 always came out in the same position relative to the TVBS A-Marker (revolution marker), only the first proton bunch, P1, could be ejected. The solution [2] was to make the $D8 a MRBS clock event. So in the new scheme, one can change the time difference between the TVBS A-Marker and the $D8 by changing the transfer cogging offset. The cogging offset can be set by the sequencer, providing reverse injection on demand. Any proton bunch can be selected. The reverse injection sequence is shown in Table 3.

# 5  Proton Injection in the Fixed Target Mode

In the fixed target mode, protons are accelerated to 150 GeV on $21 cycles. There is no coalescing and transfer cogging. The markers in the two machines are locked after MR and then a Tevatron bucket is labeled as bucket 1. Then the MRBS event $78 initiates the beam transfer. This sequence is shown in Table 4.

# 6  Appendix A

MRBS and TVBS: Beam synchronized clocks MRBS and TVBS are not really "beam synchronized". They are synchronized to RF frequencies. MRBS and TVBS generate a clock event AA (A-marker) at every 1113 RF cycles which corresponds to 159 clock ticks (7 RF cycles = 1 clock tick). The A-Marker is sometimes refered to as the "revolution marker".

| ANTIPROTON INJECTION (COLLIDER) | | |
|---|---|---|
| TCLK Event | Delay | Description |
| 00 | | Supercycle reset |
| 61 | <00> 0.1 sec | DFG:Start |
| 2A | TLG | Reset: MR cycle for collider (antiproton). |
| 40 | TLG | Reset: Antiproton injection. |
| 22 | <40> 0.6 sec | MR:Start ramp to 150 GeV. |
| 25 | <40> 2.5048 sec | MR:Start of flattop at 150 GeV. |
| | <40> 5.4 sec | Start antiproton coalescing. |
| | <40> 7.5 sec | Start the Tev time bump (handled by E0 465 cards, see Operations Bulletin 1233) |
| Sequencer complex command: "inject pbars An" (n=1-6) | | |
| C1 | | Align MRBS A-Marker with the TVBS A-Marker. Occurs only once after "setting at 150 GeV". |
| | CSBREQ request | Start transfer cogging. |
| | 984 RFCYC | Cogging offset for AP1. |
| | 242 RFCYC | Cogging offset for AP2. |
| | 427 RFCYC | Cogging offset for AP3. |
| | 613 RFCYC | Cogging offset for AP4. |
| | 798 RFCYC | Cogging offset for AP5. |
| | 56 RFCYC | Cogging offset for AP6. |
| | | Enable MRBS $7B. |
| 7B → 5B (MRBS) | <40> 13.80 sec | Initiate MR → Tev transfer. |
| | | Disable MRBS $7B. |
| end "inject pbars An" | | |
| | MRBS <7B> 0 mrev | Fire MR E17 kicker. Rise time is 6 $\mu$sec. It has a half-sine wave form. |
| | MRBS <7B> 2.396 mrev | Fire Tev D48 kicker. Rise time is 3 $\mu$sec. |
| 26 | <2A> 13.9748 sec | End of flattop (150 GeV). |

Table 2: Antiproton injection timing. Note that there is no IBMP for this cycle. The TCLK event $5B disables $40 and also triggers the Bull's Eye Plot. Kickers are referenced to MRBS $7B not TCLK $5B.

CP Cogging: The Collision Point (CP) cogging is accomplished by changing the antiproton path length. The cogging DF controller (CDFC) operates both CP cogging and transfer cogging therefore one cannot do CP cogging in the Tevatron while transfer cogging takes place in the MR RF system. The CP cogging rate cannot be varied, it is fixed at 2 buckets per second. Once initiated CP cogging always goes to completion [3]. The relevant parameters are:

T:ACPS  specifies the magnitude and direction of CP cogging. The "+" retards the antiproton beam relative to the proton beam. The antiproton pathlength becomes longer than the proton pathlength. This is accomplished by decreasing the frequency of the antiproton RF. The "-" advances the antiproton beam relative to the proton beam by increasing the Frequency of the antiproton RF. The antiproton pathlength becomes shorter.

T:MCPS  does fractional (RF bucket) CP cogging. The cogging is measured in mm units.
T:MCPCOG  starts the fractional bucket CP cogging.

# References

[1] S.Saritepe and G.Annala, "Beam Transfer at E0: An Overview", FERMILAB-TM-1790 (1993).

[2] R.J.Ducar, "Why TVBS $D8 Became MRBS $D8", Unpublished Note (July 1991).

[3] K.Meisner, "Console page M19, help subpage."

| REVERSE PROTON INJECTION | | |
|---|---|---|
| TCLK Event | Delay | Description |
| | Sequencer command | Disable $4D. Wait 8 sec. |
| 4B | Sequencer trigger | Tev:Abort clean-up |
| | Sequencer command | Disable $4B. |
| Load sequencer files 10,13 | | |
| Inject 6 coalesced proton bunches into the Tevatron on 6 $2B cycles | | |
| | Sequencer command | Tev:Move the proton lambertsons out. |
| | Sequencer command | Tev:Set the separator polarities to "-". (C:C1SVP, C:B1SHP, C:B0SHP) |
| C3 | Sequencer trigger | Open the helix. (Camac-465 tables are preloaded by C49) |
| | Sequencer command | Insert $20 cycles in the timeline. |
| 20 | TLG | Reset: MR cycle for reverse injection. |
| 22 | <20> 0.6 sec | MR:Start ramp to 150 GeV. |
| 25 | <20> 2.5048 sec | MR:Start flattop at 150 GeV. |
| | <20> 7.5 sec | Start the Tevatron time bump (handled by E0 456 cards, see Operations Bull. 1233 |
| Sequencer complex command: "eject protons Pn" (n=1-6) | | |
| | | Execute Sequencer file 35. This file sets up MR BPM events to take data on $20 cycle only. |
| C1 | | Align MRBS A-Marker with the TVBS A-Marker. Occurs only once after "setting at 150 GeV". |
| D8 → 55 (MRBS) | <20> 13.8 sec | Initiate Tev → MR transfer. |
| | <D8> 2.038 mrev | Fire the Tev D48 kicker. Rise time is 3 $\mu$sec. |
| | <D8> 1.409 mrev | Fire the MR E17 kicker. Rise time is 35 $\mu$sec. Half-sine wave form. |
| | | Disable $D8. |
| end complex command "eject protons Pn" | | |
| 26 | <20> 13.9748 sec | MR:End of $20 cycle flattop (150 GeV). |
| eject all 6 bunches, tune the antiproton injection line | | |
| C0 | Sequencer trigger | Close the helix. |
| | Sequencer command | Set C:C1SVP, C:B1SHP, C:B0SHP polarities to "+". |
| | Sequencer command | Move the proton lambertsons in. |
| | Sequencer command | Remove the $20 cycle from TLG. |

Table 3: The new reverse injection timing. The transfer cogging offsets are 0,186,371,557,742,928 RFCYC, for P1 through P6 respectively. TCLK event $55 triggers the Bull's Eye plot.

| PROTON INJECTION (FIXED TARGET) | | |
|---|---|---|
| TCLK Event | Delay | Description |
| 00 | | Supercycle reset |
| 61 | <00> 0.1 sec | DFG:Start |
| 21 | TLG | Reset: MR cycle for fixed target. |
| 4D | TLG | Reset: Proton injection. |
| 22 | <21> 0.6 sec | MR:Start ramp to 150 GeV. |
| 25 | <21> 2.5048 sec | MR:Start flattop at 150 GeV. |
| | <4D> 7.0 sec | Start the MR time bump (M:MRD46, M:MRE17). (these are now 465 cards) |
| | <4D> 7.5 sec <br> <4D> 7.8 sec | Start the T:IHTU,T:IHTD,T:IQUAD ramp <br> Start the MR time bump (T:IBMP1, T:IBMP2, T:IBMP3)(160 cards) |
| | <4D> 7.8 sec | Start the Tevatron time bump. |
| 78 → 58 (MRBS) | <4D> 13.8 sec | Initiate MR → Tev transfer. |
| | MRBS <78> 2.044 mrev | Fire MR C48 kicker. Rise time is 360 nsec. Flattop length ≈ 21$\mu$sec. |
| | MRBS <78> 1.975 mrev | Fire Tev E17 kicker. Rise time is 550 nsec. Flattop length ≈ 21$\mu$sec. |
| | | These delays take into account the transit time for the clock pulse to travel around the ring and the position of the beam relative to the clock pulse. |

Table 4: Proton injection timing in the Fixed Target operation.